

Assessing the Impact of Space Weather on the Electric Power Grid Based on Insurance Claims for Industrial Electrical Equipment

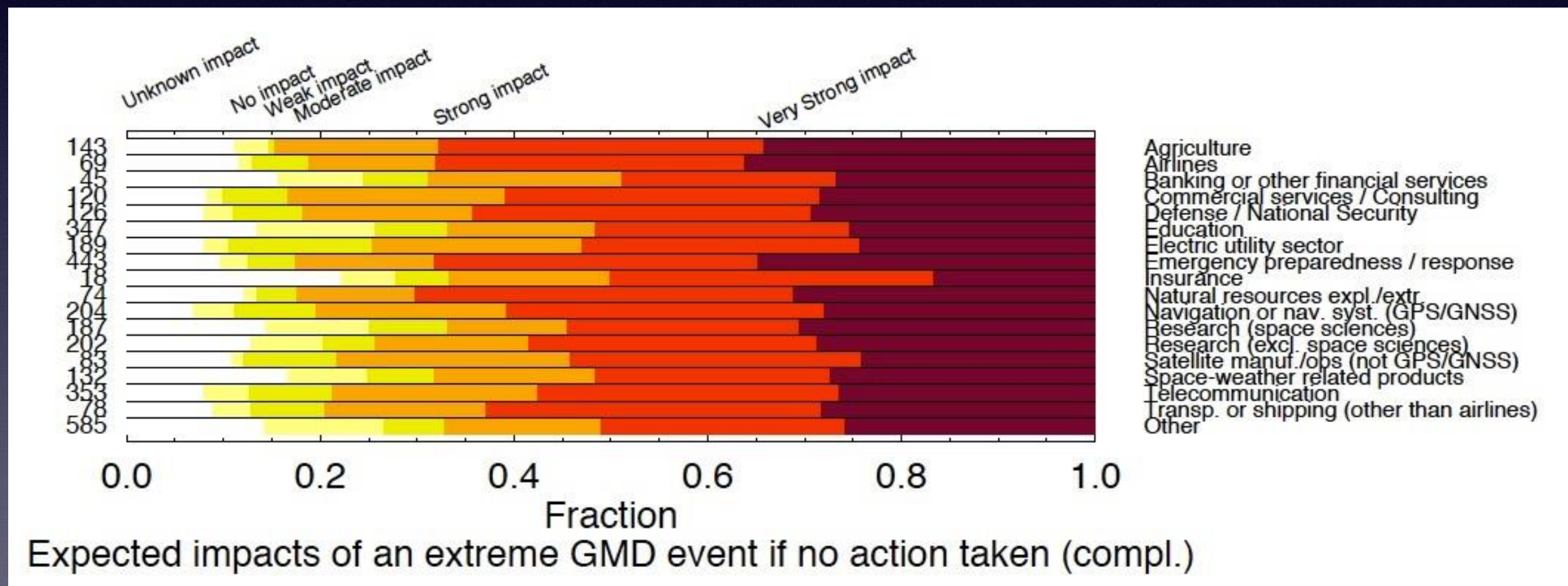
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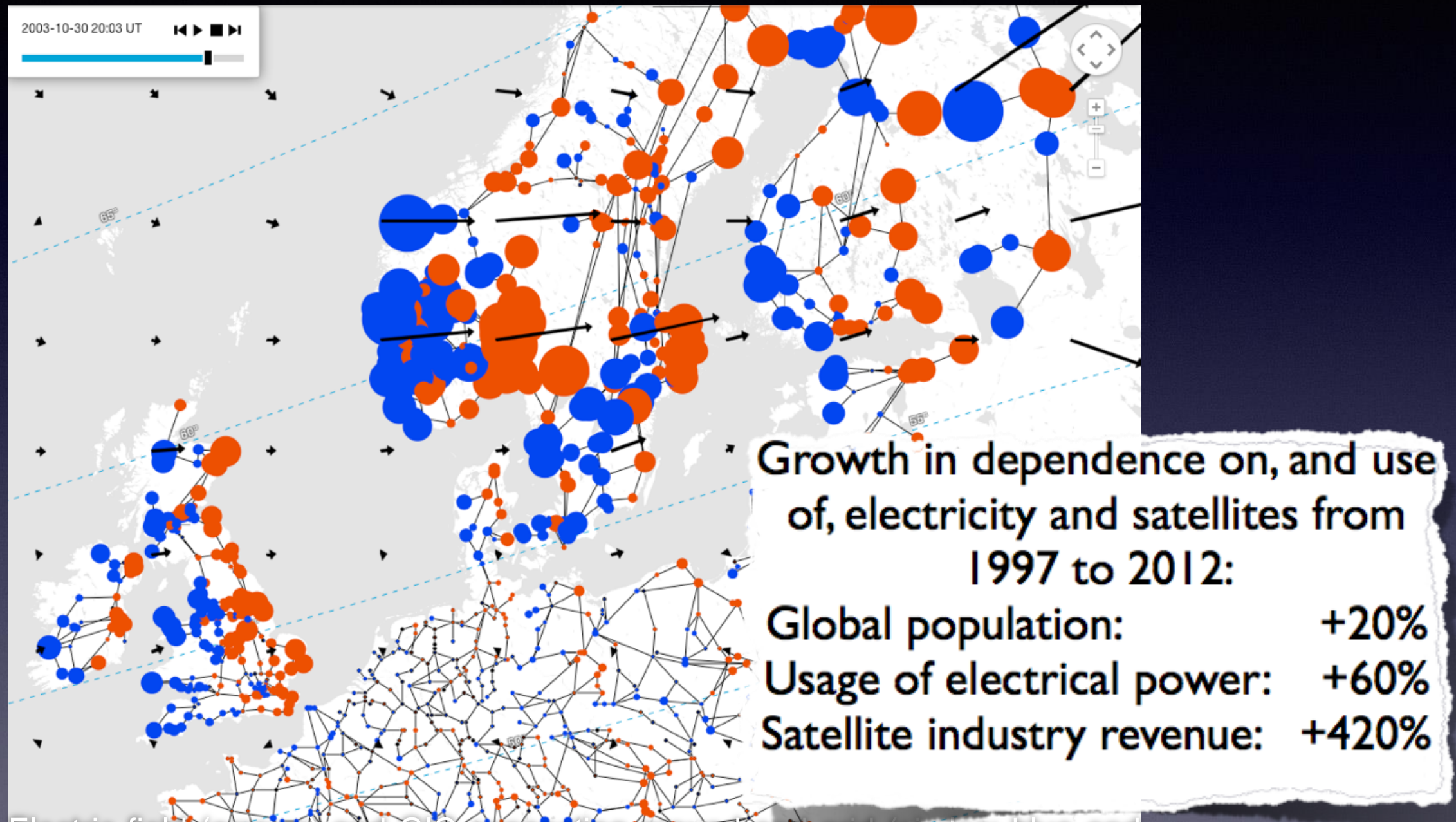
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Space weather “customers”

Some 80% of subscribers anticipate moderate to very strong consequences of a G5-class geomagnetic disturbance:



Geomagnetic variability and grid disturbances



Electric field (arrows) and GIC connecting ground and grid (circles, blue and red for opposite directions), computed from dB/dt and a model grid configuration, for the 2003/10/30 Halloween storm a few minutes before the failure in power delivery in Southern Sweden (Malmö).
Courtesy Ari Viljanen.

data visualization

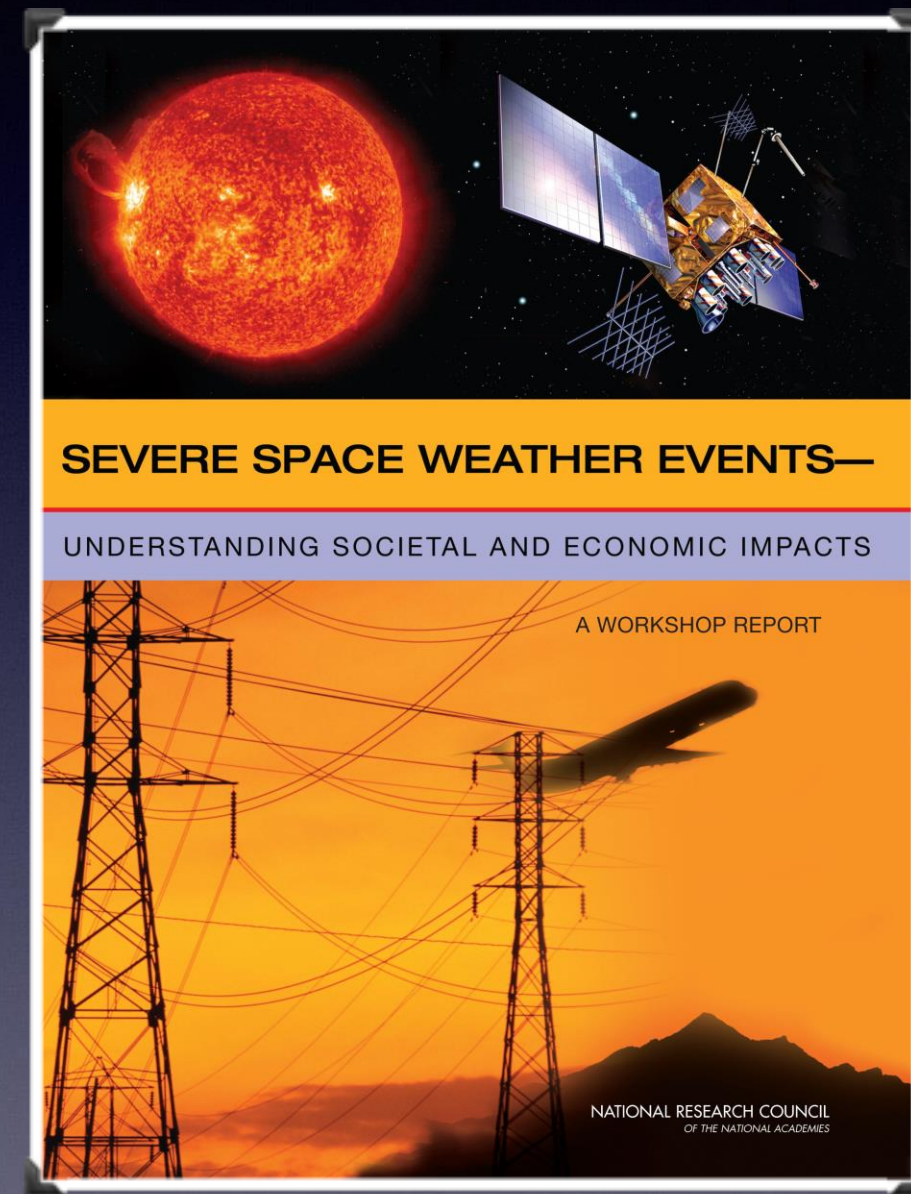
Lou Lanzaarotti (2008; doi:10.1029/2007SW000385)

- “To date, only a very few technical papers and discussions in this journal and elsewhere have addressed economic issues in space weather. And those that do have tended not to address the economics of design decisions. **I consider the absence of economic understanding of space weather impacts a serious missing link between space weather research and its applications.** Considerations of space weather and its importance to commerce and society must become more interdisciplinary in a broad sense: Economists must become interested and involved in providing the types of assessments that can aid in defining research directions and mitigation procedures.”

Space-weather impacts:

"What are the societal and economic impacts of severe space weather? [...] While this workshop, along with its report, has gathered in one place much of what is currently known or suspected about societal and economic impacts, it has perhaps been most successful in illuminating the scope of the myriad issues involved, and the gaps in knowledge that remain to be explored in greater depth than can be accomplished in a workshop. A quantitative and comprehensive assessment of the societal and economic impacts of severe space weather will be a truly daunting task [...]"

"[...] an estimate of \$1 trillion to \$2 trillion during the first year alone was given for the societal and economic costs of a “severe geomagnetic storm scenario” with recovery times of 4 to 10 years."



Potential Impacts of a major geomagnetic storm

- For a “Quebec- and Carrington-like” event: Assuming 10% of electricity supply is lost for one year, with Leontief’s input-output (IO) theory and associated tables:
 - American storm: US\$ 2.4 trillion
 - European storm: US\$ 3.4 trillion
 - Asia-centered storm: US\$ 3.1 trillion

“The global economic damage is of the same order as wars, extreme financial crisis and estimated for future climate change.”

From H. Schulte in den Bäumen, D. Moran, M. Lenzen, I. Cairns, and A. Steenge; Nat. Hazards Earth Syst. Sci., 14, 2749–2759, 2014 Nat. Hazards Earth Syst. Sci., 14, 2749–2759, 2014

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H. Schulte in den Bäumen et al.: How severe space weather can disrupt global supply chains

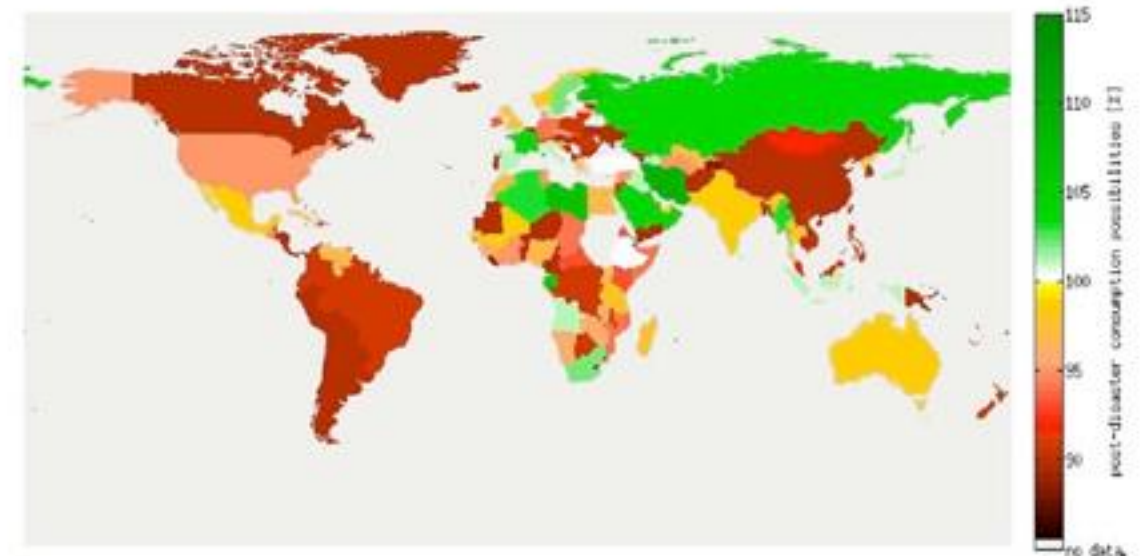
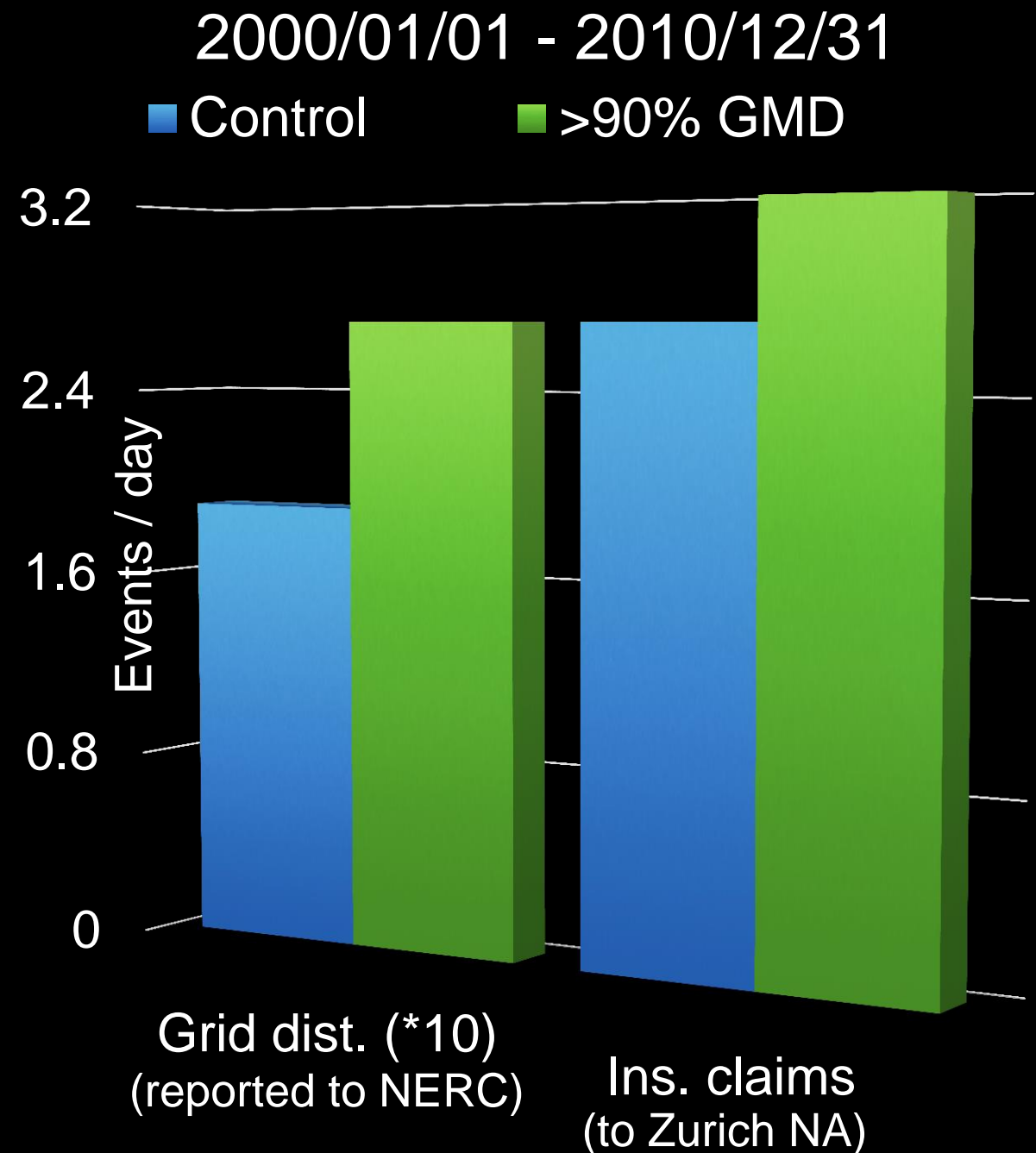


Figure 3. Effects of scenario 1, a Quebec 1989-like event centered over the Americas. Globally, the storm would reduce total consumption possibilities by 3.9 % though the effect is uneven: it is most severe in countries directly affected and their economic partners, while other countries (e.g., Russia, Saudi Arabia, France, and Egypt) may gain consumption possibilities in the post-disaster economy.

Effects of GMD on US power grid

- The 'moderate' geomagnetic storms of the past decade have impacts on the power grid and on the economy through 'grid disturbances' and insurance claims: it does not take a major storm for measurable effects:
- On top 10% of geomagnetically active dates; ~20% increase in insurance claims.



From C. J. Schrijver, R. Dobbins, W. Murtagh, and S. M. Petrinec; *Space Weather*, 2014 DOI 10.1002/2014SW001066

Example of impacts: power grids

Grid disturbance reports and insurance claims reveal that geomagnetic disturbances contribute to, if not directly cause, power-quality variations with economic impacts, even in non-extreme conditions.

Estimated impacts of “power outages and power quality disturbances” to the overall economy:

US: **US\$100–180 billion/year** (from a study commissioned by the US Electric Power Research Institute, 2001)

25-country EU: approx. **€ 150 billion/year** (from a study by Manson and Targosz, 2008)

GDP impacts of common space weather via low-voltage electrical grid inferred via insurance claims for electrical/electronic industrial equipment is likely ~5% of total, i.e., **~US\$5–10 billion/year**.

[roughly comparable to the total of a century-level extreme event!]

Schrijver (LMA/PC), Dobbins (Zurich NA), Mullanagh (NOAA/SWPC), Petrinec (LM STAR Labs), 2014, Space Weather

How severe can space weather storms be?

- Observations of Sun-like stars suggest that solar flares may reach energies up to 100-300 times above those observed in the past four decades.
 - Ice and rocks from Earth and Moon tell us that energetic particle storm intensities appear to saturate at a few times the space-age maximum.
 - Theory of geomagnetic storms suggests they may not be able to exceed twice the strength of the powerful 1859 Carrington event (*which may not be as rare as once thought: consider the 2012/07/23 heliospheric storm that missed Earth**), at least not when using Dst as a metric.
- All these potential extremes exceed the levels to which modern technologies, connected in a network of growing complexity, have been exposed.

Reviewed by Schrijver & Beer, 2014; EOS, v. 95, no. 24, pp. 201-208

* Baker et al., 2013, Space Weather Journal, DOI: 10.1002/swe.20097: "extreme space weather conditions such as those during March of 1989 or September of 1859 can happen even during a modest solar activity cycle"

International roadmap

Improving understanding and forecasts of space weather requires addressing scientific challenges within the network of physical processes that connect the Sun to society. The roadmap team identified the highest-priority areas within the Sun-Earth space-weather system whose advanced understanding is urgently needed. The roadmap recommends actions towards such advanced understanding, focusing on the general infrastructure to support research as well as on specific concepts for instrumentation to meet scientific needs.

General recommendations:

Research: observational, computational, and theoretical needs

- Advance the international Sun-Earth system observatory along with models to improve forecasts based on understanding of real-world events through the development of innovative approaches to data incorporation, including data-driving, data assimilation, and ensemble modeling;
- Understand space weather origins at the Sun and their propagation in the heliosphere, initially prioritizing post-event solar eruption modeling to develop multi-day forecasts of geomagnetic disturbance times and strengths, after propagation through the heliosphere;
- Understand the factors which control the generation of geomagnetically-induced currents (GICs) and of harsh radiation in geospace, involving the coupling of the solar wind disturbances to internal magnetospheric processes in the magnetosphere and the ionosphere below;
- Develop a comprehensive space environment specification for research and engineering designs, later to support operational needs.

Teaming: coordinated collaboration

- Quantify vulnerability of humans and critical infrastructure by partnering with user groups;
- Build test beds in which coordinated observations and modeling can be used to validate models;
- Standardize (meta-)data and products to enable interoperability of model archives;
- Optimize observational coverage of the Sun-Earth system.

Collaboration between agencies

- Implement open space-weather data and information policy;
- Provide access to quality education & information materials;
- Execute an international, inter-agency assessment on a 5-yr basis to adjust priorities and to guide research and development;
- Develop settings to transition research models to operations;
- Partner with the weather and solid-Earth communities.

The roadmap's research recommendations (see reverse of this flier) that reflect a blend of the maximum scientific need, technological feasibility, and likelihood of success. The needs recommendations of preceding one(s) impact the current recommendations but can be initiated in parallel. The pathways are differential needs of the user communities working with space weather.

Differential needs and recommendations for next steps towards a global road map for 2015-2025

Character of requirements	Most significant use:	Electrical systems	Navigation/Positioning
		Geomagnetic variability protection of electrical & electronic systems	Reliability of navigation and communication systems
Knowledge of environment for system design		Pathway 1	Pathway 1
Near-real time info and short-term forecasts		Pathway 1	Pathway 1
1-2 day forecasts		Pathway 1	Pathway 1
		Pathway 1	Pathway 3

Concepts for priority new instrumentation for Pathways I,II,III

The recommendations in Pathways I, II, and III (see reverse of this flier) result in focus questions and associated concepts for new space missions and ground observatories that complement existing resources in the international Sun-Earth system observatory. For each pathway in order of priority:

Pathway I-1: Quantify active-region magnetic structure for nascent coronal ejections.

Binocular vision for the corona. The quantitative description of the solar magnetic field in coronal mass ejections requires surface field maps plus stereoscopic coronal imaging at ~1 arcsec resolution. To forecast geomagnetic storm strengths more than 12 hrs ahead: EUV images from ~10"-20" off the Sun-Earth line matching those from Earth perspective, with contiguous coronagraph images.

3D mapping of solar field involved in eruptions. Knowing the filament configuration and its embedding field in the corona is key to feeding heliospheric models. Mapping the multi-thermal plasma surface at high-resolution provides critical information for forecasting.

Pathway II-1: Understand solar wind-magnetosphere-ionosphere coupling dynamics.

Understanding space weather to shield society
A global road map for 2015-2025
commissioned by COSPAR and ILWS

Look for it in
Advances in Space Research
and at
<http://tinyurl.com/swxrm>
<http://arxiv.org/abs/1503.06135>

Pathway III-1: Quantify active-region magnetic structure for nascent coronal ejections.

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Understanding space weather to shield society

2014/10/24

An international, interdisciplinary roadmap to advance the scientific understanding of the Sun-Earth connections leading to space weather, commissioned by COSPAR and the International Living With a Star program

www.cnes.fr/scientific-structure/cospar-scientific-roadmaps
www.swxrm.com

Recommendations in brief:

- Advance the international Sun-Earth system observatory along with approaches to data incorporation;
- Understand space weather origins at the Sun and their propagation in the heliosphere;
- Control the geospace response; develop space environment specification;
- Develop a comprehensive space environment specification;
- Develop a coordinated observing supports model;
- Develop product metrics, and harmonize access to data and information;
- Develop a policy of the Sun-society system;
- Develop a space-weather data and information policy;
- Develop a policy to quality education & information materials;
- Develop the state of the field on a 5-yr basis to adjust priorities and to guide international coordination;
- Develop settings to transition research models to operations;
- Strengthen partnerships to share lessons-learned.

Highest-priority research areas to improve space weather information:

1. Quantify active-region magnetic structure to model nascent coronal mass ejections;
2. Understand solar wind-magnetosphere-ionosphere coupling dynamics inducing strong currents;
3. Know the global coronal field to drive models of the solar-wind plasma and magnetic field from Sun to Earth;
4. Learn to quantify the state of the coupled magnetosphere-ionosphere system;
5. Understand the radiation belts through dynamic observation-based modeling;
6. Understand solar energetic particles throughout the Sun-Earth system.

Deployment of new/additional instrumentation, to add to existing observational resources and to modeling capabilities to be developed soon:



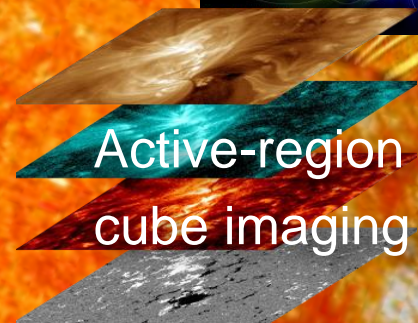
Binocular vision for the solar corona

I-1: Quantify active-region magnetic structure for nascent coronal ejections



Radiation belt models

II: Data-driven dynamic radiation-belt modeling



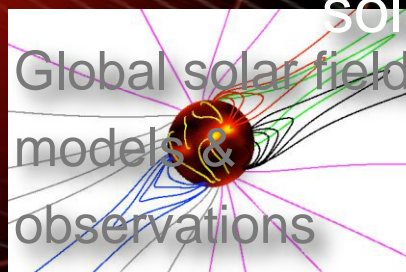
Active-region cube imaging



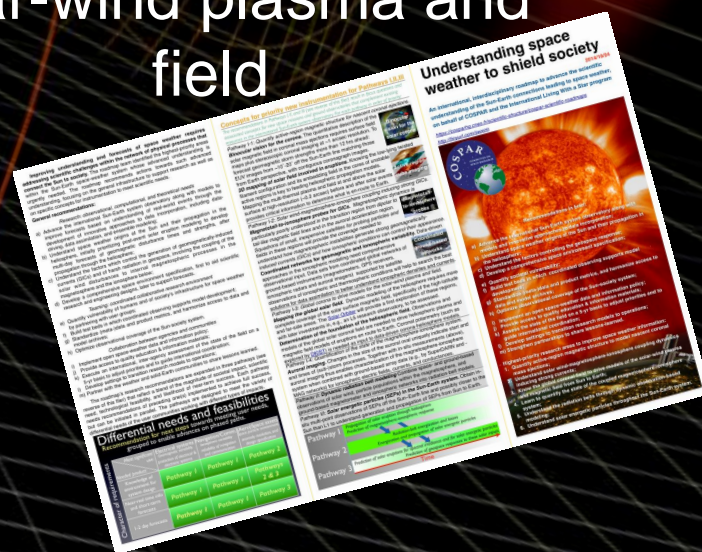
In-situ SEP measurements in inner heliosphere

III: Solar energetic particles in the Sun-Earth system

I-3: Global corona to drive models for the solar-wind plasma and field



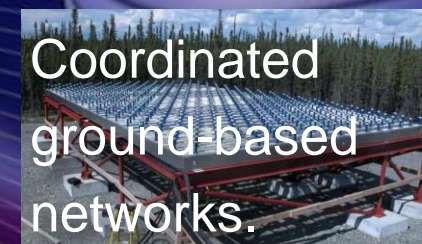
Global solar field models & observations



I-2: Solar wind-magnetosphere-ionosphere coupling inducing strong GICs



Magnetotail-to-ionosphere probes



Coordinated ground-based networks.

I-4: Quantification of the state of the magnetosphere-ionosphere system

